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DESCRIPTION

VACUUM PUMP AND METHOD OF STARTING THE SAME

Technical Field

The present invention relates to a vacuum pump and a method of starting a vacuum pump, and more particularly to a vacuum pump for evacuating a gas from a chamber used in a semiconductor fabrication apparatus or the like, and a method of starting such a vacuum pump.

Background Art

In a semiconductor fabrication apparatus, a vacuum pump is widely used for evacuating a gas used in a semiconductor fabrication process from a chamber and producing a vacuum environment in the chamber. As this type of vacuum pump, there has been known a positive-displacement vacuum pump having Roots-type or screw-type pump rotors.

Generally, the positive-displacement vacuum pump comprises a pair of pump rotors disposed in a casing, and a motor for rotating the pump rotors. A small clearance is formed between the pair of the pump rotors themselves and also between the pump rotors and the inner surface of the casing so that the pump rotors are rotated in a noncontact manner. When the pair of the pump rotors are synchronously rotated in the opposite directions by energizing the motor, a gas drawn from an inlet port into the casing is delivered toward an outlet port and is thus evacuated from a chamber or the like connected to the inlet port of the vacuum pump.

Some gases used in the semiconductor fabrication process contain components which are solidified or liquidized when the temperature of the gases is lowered. Generally, in the above positive-displacement vacuum pump, the heat of compression is generated during the process of delivering the gas toward the

outlet port, and hence the vacuum pump has a high temperature during operation. Therefore, while the vacuum pump maintains a high temperature, even if the vacuum pump evacuates the gas containing the above components, the components are not solidified or liquidized, and a good evacuation is thus carried out.

However, when the operation of the vacuum pump is stopped and the temperature of the vacuum pump is gradually lowered, the components contained in the gas are solidified or liquidized, and are deposited in the clearance between the pump rotors and between the pump rotors and the casing (hereinafter, the solidified or liquidized components are refereed to as a product). Consequently, such product prevents the rotation of the pump rotors, and hence the pump rotors cannot be rotated by a starting torque of the motor, thus causing a failure of the restart of the vacuum pump. Further, in addition to the failure of the restart of the vacuum pump, an excessive load is applied to the motor to cause the motor to overheat, and hence the vacuum pump cannot be operated safely.

Furthermore, in recent years, there has been developed a motor-drive technique for driving an induction motor, a brushless DC motor, or the like with the use of an inverter such as a frequency converter. If such a motor-drive technique is used in the vacuum pump, a torque of the motor for starting the vacuum pump is limited by capacities of parts used in the inverter. Consequently, the motor can generate only a limited torque, and the starting operation of the vacuum pump tends to be more difficult.

Disclosure of Invention

The present invention has been made in view of the above drawbacks. It is therefore an object of the present invention to provide a vacuum pump which can be normally started even if

a product solidified or liquidized in a casing of the vacuum pump presents an obstacle to the rotation of the pump rotor.

Another object of the present invention is to provide a method of starting such a vacuum pump.

In order to achieve the above object, according to one aspect of the present invention, there is provided a vacuum pump comprising: a pump rotor rotatably disposed in a casing; and a pump-rotor controller for controlling rotation of the pump rotor in a forward direction or a reverse direction in accordance with a predetermined pattern at the time of starting the vacuum pump. The rotation of the pump rotor in the forward direction is defined as the rotation of the pump rotor in a direction in which a gas drawn in the casing is delivered from an inlet side of the casing toward an outlet side of the casing. The rotation of the pump rotor in the reverse direction is defined as the rotation of the pump rotor in a direction opposite to the forward direction.

In a preferred aspect of the present invention, the predetermined pattern includes a combination of at least two of rotation of the pump rotor in the forward direction, rotation of the pump rotor in the reverse direction, and stop of the pump rotor.

In a preferred aspect of the present invention, the predetermined pattern is set in the pump-rotor controller such that the pump rotor is driven in the order of the rotation in the forward direction, the stop, and the rotation in the forward direction.

In a preferred aspect of the present invention, the predetermined pattern is set in the pump-rotor controller such that the pump rotor is rotated in the order of the reverse direction and the forward direction.

According to the present invention, if the product solidified or liquidized in the casing prevents the rotation

of the pump rotor, the pump rotor is rotated in accordance with a predetermined pattern to thereby remove the product, thus enabling the vacuum pump to be started normally.

In a preferred aspect of the present invention, the vacuum pump further comprises a state-judging device for judging whether the pump rotor is rotated normally or not at the time of starting the vacuum pump; wherein when the state-judging device judges that the pump rotor is not rotated normally at the time of starting the vacuum pump, the pump rotor is rotated in accordance with the predetermined pattern.

According to the present invention, when the pump rotor can be rotated normally, a normal-starting operation is carried out, thus enabling the vacuum pump to be started quickly.

According to another aspect of the present invention, there is provided a method of starting a vacuum pump having a pump rotor rotatably disposed in a casing, comprising: controlling rotation of the pump rotor in a forward direction or a reverse direction at the time of starting the vacuum pump in accordance with a predetermined pattern; and rotating the pump rotor in the forward direction in a steady state for evacuation.

In a preferred aspect of the present invention, the predetermined pattern includes a combination of at least two of rotation of the pump rotor in the forward direction, rotation of the pump rotor in the reverse direction, and stop of the pump rotor.

In a preferred aspect of the present invention, the predetermined pattern is set such that the pump rotor is driven in the order of the rotation in the forward direction, the stop, and the rotation in the forward direction.

In a preferred aspect of the present invention, the predetermined pattern is set such that the pump rotor is rotated in the order of the reverse direction and the forward direction.

In a preferred aspect of the present invention, a method

of starting a vacuum pump further comprises judging whether the pump rotor is rotated normally or not; wherein the pump rotor is rotated in accordance with the predetermined pattern when the pump rotor is judged not to be rotated normally.

According to another aspect of the present invention, there is provided a method of starting a vacuum pump, comprising: judging whether the pump rotor is rotated normally or not; controlling rotation of the pump rotor in a forward direction or a reverse direction at the time of starting the vacuum pump in accordance with a predetermined pattern when the pump rotor is judged not to be rotated normally; and rotating the pump rotor in the forward direction in a steady state for evacuation.

Brief Description of Drawings

FIG. 1 is a cross-sectional view showing a vacuum pump according to a first embodiment of the present invention;

FIG. 2 is a schematic view showing a control system including a pump-rotor controller according to the first embodiment of the present invention;

FIG. 3 is a schematic view showing a control system including a pump-rotor controller according to a second embodiment of the present invention;

FIG. 4 is a schematic view showing a control system including a pump-rotor controller according to a third embodiment of the present invention;

FIG. 5 is a schematic view showing a control system including a pump-rotor controller according to a fourth embodiment of the present invention; and

FIG. 6 is a schematic view showing a control system including a pump-rotor controller according to a fifth embodiment of the present invention.

Best Mode for Carrying Out the Invention

A vacuum pump and a method of starting a vacuum pump according to embodiments of the present invention will be described below with reference to the drawings.

Although a vacuum pump according to the present embodiments is used for evacuating a gas from a chamber used in a semiconductor fabrication apparatus, the present invention is not limited to such an application. FIG. 1 is a cross-sectional view showing a vacuum pump according to a first embodiment of the present invention.

As shown in FIG. 1, the vacuum pump according to the first embodiment comprises a pair of pump rotors 1, 1 each having a screw groove, a casing 2 for housing the pump rotors 1, 1, and a motor 3 for rotating the pump rotors 1, 1. The casing 2 has an inlet port 7 for drawing a gas therein and an outlet port 8 for discharging the gas therefrom. The pump rotors 1, 1 are fixed respectively to two shafts 4, 4 which are rotatably supported by bearings 5, 5.

One of the shafts 4, 4 has a motor rotor 3a fixed thereto, and a motor stator 3b is disposed so as to enclose the motor rotor 3a. The motor rotor 3a and the motor stator 3b constitute the motor 3. In this embodiment, the motor 3 comprises an induction motor. Timing gears 6, 6 are fixed to end portions of the shafts 4, 4, respectively, and the pair of the pump rotors 1, 1 are synchronously rotated in the opposite directions by the timing gears 6, 6. A small clearance is formed between the pair of the pump rotors 1, 1 themselves and also between the pump rotors 1, 1 and the inner surface of the casing 2 so that the pump rotors 1, 1 are rotated in a noncontact manner.

With the above structure, when the pair of the pump rotors 1, 1 are rotated by energizing the motor 3, a gas is drawn from the inlet port 7 and delivered from an inlet side to an outlet side of the casing 2 along the screw grooves of the engaging

pump rotors 1, 1, and is then discharged from the outlet port 8. In this manner, the gas is continuously delivered from the inlet side to the outlet side, thereby evacuating the gas from a chamber (not shown in the drawings) connected to the inlet port 7. The chamber is incorporated in a semiconductor fabrication apparatus.

As shown in FIG. 1, the vacuum pump of this embodiment comprises a control system 10 for controlling the operation of the vacuum pump. The control system 10 incorporates a pump-rotor controller 15 therein for controlling rotation of the pump rotors 1, 1 and stop of the pump rotors 1, 1.

FIG. 2 is a schematic view showing the control system including the pump-rotor controller according to the first embodiment of the present invention.

As shown in FIG. 2, the control system comprises a three-phase power source 11, an earth leakage breaker (ELB) 12, an electromagnetic contactor 13, and a thermal protector 14. The three-phase power source 11 is connected to the electromagnetic contactor 13 through the earth leakage breaker (ELB) 12, and the electromagnetic contactor 13 is connected to the motor 3 through the thermal protector 14. The pump-rotor controller 15 for controlling the rotation of the pump rotors 1, 1 (only one pump rotor is schematically shown in FIG. 2) and the stop of the pump rotors 1, 1 is connected to the electromagnetic contactor 13. A circuit breaker (CB) may be used instead of the earth leakage breaker (ELB) 12.

A start-switch (not shown) of the vacuum pump is connected to the pump-rotor controller 15, and when the start-switch is operated, a start-command signal is sent from the pump-rotor controller 15 to the electromagnetic contactor 13. The electromagnetic contactor 13 is activated in response to the start-command signal, and a three-phase voltage is applied to the motor 3 from the three-phase power source 11. Therefore,

a rotational torque for rotating the pump rotors 1, 1 in forward directions is imparted to the pump rotors 1, 1 from the motor 3, thus starting the vacuum pump. The thermal protector 14 is provided for breaking current supplied from the three-phase power source 11 to stop the operation of the vacuum pump when the motor 3 is overloaded, thus preventing the overload and the overheat of the motor 3 from occurring.

The pump-rotor controller 15 includes a timer 16, and when the vacuum pump is started, the pump rotors 1, 1 are rotated or stopped in accordance with a predetermined pattern set in the timer 16 in advance. In this embodiment, the pattern of the timer 16 is set such that the pump rotors 1, 1 are driven in the order of (1) forward-direction rotation (rotation of the pump rotors 1, 1 in the forward directions), (2) stop, and (3) forward-direction rotation. When the pump rotors 1, 1 are rotated in the forward directions, one of the pump rotors 1, 1 is rotated in one direction (e.g. clockwise direction) and another pump rotor 1 is rotated in the opposite direction (e.g. counterclockwise direction). In this case, the gas is drawn from the inlet port 7 into the casing 2, and delivered toward the outlet port 8 and discharged from the outlet port 8. The rotation of the pump rotors 1, 1 in the forward directions is defined as the rotation of the pump rotors 1, 1 in directions in which the gas drawn in the casing 2 is delivered from the inlet port 7 toward the outlet port 8.

Therefore, when the vacuum pump is started, first, the rotational torque for rotating the pump rotors 1, 1 in the forward directions is imparted to the pump rotors 1, 1 from the motor 3. Thereafter, the rotational torque imparted to the pump rotors 1, 1 is reduced to zero once. Subsequently, the rotational torque for rotating the pump rotors 1, 1 in the forward directions is imparted to the pump rotors 1, 1 from the motor 3 again.

In this manner, when the vacuum pump is started, the pump

rotors 1, 1 are rotated and then stopped, and are rotated again. Therefore, forces of the pump rotors 1, 1 can be applied to a product deposited in the clearance between the pump rotors 1, 1 and the casing 2. As a result, the product which has been solidified is embrittled and removed, thus enabling the vacuum pump to be started normally. In the case where a pattern for allowing the pump rotors 1, 1 to repeat its rotation and stop several times is set in the timer 16, the reliability of removal of the product can be further enhanced. After the vacuum pump is started normally, the pump rotors 1, 1 are rotated in the forward directions in a steady state for evacuation.

Next, a vacuum pump and a method of starting a vacuum pump according to a second embodiment of the present invention will be described with reference to FIG. 3. The basic structure of a vacuum pump of this embodiment is the same as that of the first embodiment, and will not be described in detail below.

FIG. 3 is a schematic view showing a control system including a pump-rotor controller according to the second embodiment of the present invention.

As shown in FIG. 3, a control system of this embodiment comprises a three-phase power source 11, an earth leakage breaker (ELB) 12, and a frequency converter 21. The three-phase power source 11 is connected to the frequency converter 21 through the earth leakage breaker (ELB) 12, and the frequency converter 21 is connected to the motor 3. The frequency converter 21 comprises a rectifier 22, a power transistor 23 for generating a waveform to rotate the motor 3, and a frequency-conversion controller 24 for controlling the frequency converter 21. A pump-rotor controller 15 for controlling rotation of the pump rotors 1, 1 and stop of the pump rotors 1, 1 is connected to the frequency converter 21.

The pump-rotor controller 15 includes a timer 16, as with the first embodiment. Specifically, when a start-switch (not

shown) is operated, a start-command signal is sent from the pump-rotor controller 15 to the frequency converter 21, and a three-phase voltage is applied to the motor 3 from the three-phase power source 11. Thus, the pump rotors 1, 1 are rotated in accordance with a predetermined pattern set in the timer 16 in advance. In this embodiment, as with the first embodiment, the pattern is set in the timer 16 such that the pump rotors 1, 1 are driven by the motor 3 in the order of (1) forward-direction rotation, (2) stop, and (3) forward-direction rotation. A pattern for allowing the pump rotors 1, 1 to repeat its rotation and stop several times may be set in the timer 16.

Although an induction motor is used as the motor 3 in this embodiment, the induction motor can be replaced with a brushless DC motor by replacing the frequency-conversion controller 24 with a brushless-DC-motor controller. In this case also, as in the case of the induction motor, the pump rotor can be rotated in accordance with a predetermined pattern.

Next, a vacuum pump and a method of starting a vacuum pump according to a third embodiment of the present invention will be described with reference to FIG. 4. The basic structure of a vacuum pump and parts of a control system denoted by identical reference numerals are the same as those of the first embodiment, and will not be described in detail below.

FIG. 4 is a schematic view showing a control system including a pump-rotor controller according to the third embodiment of the present invention.

As shown in FIG. 4, a control system comprises a three-phase power source 11, an earth leakage breaker (ELB) 12, a first electromagnetic contactor 13A, a second electromagnetic contactor 13B, and a thermal protector 14. An induction motor is used as the motor 3. The first electromagnetic contactor 13A and the second electromagnetic contactor 13B are connected to a pump-rotor controller 15, respectively, and are activated by

receiving an operation-command signal from the pump-rotor controller 15. The three-phase power source 11 is connected to the first electromagnetic contactor 13A and the second electromagnetic contactor 13B through the earth leakage breaker (ELB) 12, and the first electromagnetic contactor 13A and the second electromagnetic contactor 13B are connected to the motor 3 through the thermal protector 14. The first electromagnetic contactor 13A applies a three-phase voltage of the three-phase power source 11 to the motor 3 with the phase sequence being kept as it is. On the other hand, the second electromagnetic contactor 13B applies the three-phase voltage of the three-phase power source 11 with the phase sequence being inverted from the phase sequence of the three-phase voltage of the three-phase power source 11.

The pump-rotor controller 15 is constructed so as to rotate the pump rotors 1, 1 in forward directions or reverse directions in accordance with a predetermined pattern set in the pump-rotor controller 15 in advance through the first electromagnetic contactor 13A and the second electromagnetic contactor 13B. Specifically, an operation-command signal is sent from the pump-rotor controller 15 to the first electromagnetic contactor 13A and the second electromagnetic contactor 13B alternately in accordance with the predetermined pattern. The pattern is set in the pump-rotor controller 15 such that the pump rotors 1, 1 are rotated in the order of the reverse directions and the forward directions. When the pump rotors 1, 1 are rotated in the forward directions, one of the pump rotors 1, 1 is rotated in one direction (e.g. clockwise direction) and another pump rotor 1 is rotated in the opposite direction (e.g. counterclockwise direction). In this case, the gas is drawn from the inlet port 7 into the casing 2 and discharged from the outlet port 8. On the other hand, when the pump rotors 1, 1 are rotated in the reverse directions, the pump rotors 1, 1 are rotated

in directions opposite to the directions of the pump rotors 1, 1 which are rotated in the forward directions. The rotation of the pump rotors 1, 1 in the reverse directions is defined as the rotation of the pump rotors 1, 1 in directions opposite to the forward directions.

The operation of the vacuum pump having the above structure of this embodiment will be described in detail below. When a start-switch (not shown) of the vacuum pump is operated, first, the operation-command signal is sent from the pump-rotor controller 15 to the second electromagnetic contactor 13B. By activating the second electromagnetic contactor 13B, the three-phase voltage having an inverted phase sequence is applied to the motor 3 through the second electromagnetic contactor 13B, and hence the rotational torque for rotating the pump rotors 1, 1 in the reverse directions is imparted to the pump rotors 1, 1 from the motor 3. Thereafter, the pump-rotor controller 15 stops sending the operation-command signal to the second electromagnetic contactor 13B. At the same time, the operation-command signal is sent from the pump-rotor controller 15 to the first electromagnetic contactor 13A. By activating the first electromagnetic contactor 13A, the three-phase voltage of the three-phase power source 11 is applied to the motor 3 through the first electromagnetic contactor 13A with the phase sequence being kept as it is. Therefore, the rotational torque for rotating the pump rotors 1, 1 in the forward directions is imparted to the pump rotors 1, 1 from the motor 3.

In this manner, by rotating the pump rotors 1, 1 in the reverse directions or the forward directions at the time of starting the vacuum pump, the forces of the pump rotors 1, 1 can be applied to the product deposited in the gap between the pump rotors 1, 1 and the casing 2. As a result, the product is removed, thus enabling the vacuum pump to be started.

Next, a vacuum pump and a method of starting a vacuum pump

according to a fourth embodiment of the present invention will be described with reference to FIG. 5. The basic structure of a vacuum pump and parts of a control system denoted by identical reference numerals are the same as those of the second embodiment, and will not be described in detail below.

FIG. 5 is a schematic view showing a control system including a pump-rotor controller according to the fourth embodiment of the present invention.

As shown in FIG. 5, a pump-rotor controller 15 is constructed so as to send a start-command signal 101 for starting the vacuum pump and a control signal 102 for rotating the pump rotors 1, 1 in the forward directions or the reverse directions in accordance with a predetermined pattern to the frequency-conversion controller 24 of the frequency converter 21. A pattern is set in the pump-rotor controller 15 such that the pump rotors 1, 1 are rotated in the order of the reverse directions and the forward directions at the time of starting the vacuum pump, as with the third embodiment.

The control system of this embodiment shown in FIG. 5 is operated to start the vacuum pump as follows: When a start-switch (not shown) is operated, the start-command signal 101 is sent from the pump-rotor controller 15 to the frequency-conversion controller 24. At the same time, the control signal 102 for rotating the motor 3 in the reverse direction is sent from the pump-rotor controller 15 to the frequency-conversion controller 24. Therefore, the rotational torque for rotating the pump rotors 1, 1 in the reverse directions is imparted to the pump rotors 1, 1 from the motor 3. Thereafter, the control signal 102 for rotating the motor 3 in the forward direction is sent from the pump-rotor controller 15 to the frequency-conversion controller 24, and hence the rotational torque for rotating the pump rotors 1, 1 in the forward directions is imparted to the pump rotors 1, 1 from the motor 3.

Although an induction motor is used as the motor 3 in this embodiment, the induction motor can be replaced with a brushless DC motor by replacing the frequency-conversion controller 24 with a brushless-DC-motor controller. In this case also, as in the case of the induction motor, the pump rotors 1, 1 can be rotated in the forward directions or the reverse directions in accordance with a predetermined pattern.

Next, a vacuum pump and a method of starting a vacuum pump according to a fifth embodiment of the present invention will be described with reference to FIG. 6. The basic structures of a vacuum pump and a control system of this embodiment are the same as those of the fourth embodiment, and will not be described in detail below.

FIG. 6 is a schematic view showing a control system including a pump-rotor controller according to the fifth embodiment of the present invention.

The vacuum pump of this embodiment comprises a current monitor 27 for monitoring current supplied to the motor 3. The current monitor 27 serves as a state-judging device for judging whether the pump rotors 1, 1 are rotated normally or not at the time of starting the vacuum pump. When the current monitor 27 detects that current supplied to the motor 3 is in an abnormal state, the current monitor 27 judges that the pump rotors 1, 1 are not rotated normally. Specifically, if the product or the like deposited in the casing 2 prevents the pump rotors 1, 1 from being rotated, current supplied to the motor 3 is detected to be in the abnormal state, and hence the current monitor 27 can judge that the pump rotors 1, 1 are not rotated normally.

Further, when the current monitor 27 judges that the rotation of the pump rotors 1, 1 is abnormal, the current monitor 27 sends an operation signal to the pump-rotor controller 15. The pump-rotor controller 15 is activated by receiving the operation signal to thereby rotate the motor 3 in accordance

with a predetermined pattern which is set in the pump-rotor controller 15 in advance.

Specifically, in this embodiment, the pump-rotor controller 15 does not work until the operation signal is sent from the current monitor 27 to the pump-rotor controller 15. Therefore, when the pump rotor can be rotated normally, the normal-starting operation is carried out, thus enabling the vacuum pump to be started quickly.

As a state-judging device, a rotation monitor for monitoring the rotation of the pump rotors 1, 1 or a product monitor for monitoring the amount of the product deposited in the casing 2 may be provided instead of the current monitor 27. In the case where the product monitor is provided, an optical sensor or a thermocouple may be used for monitoring the amount of the product deposited in the casing 2. In this case, when the amount of the product is increased to a predetermined value, the product monitor may send the operation signal to the pump-rotor controller 15.

Although the vacuum pump according to the embodiments of the present invention has two pump rotors engaging with each other, the present invention can be applied to a vacuum pump having a single pump rotor or more than two pump rotors. In these cases also, the rotation of the pump rotor (or pump rotors) in a forward direction (or forward directions) is defined as the rotation of the pump rotor (or pump rotors) in a direction (or directions) in which a gas is delivered from an inlet side toward an outlet side. The rotation of the pump rotor (or pump rotors) in a reverse direction (or reverse directions) is defined as the rotation of the pump rotor (or pump rotors) in a direction (or directions) opposite to the forward direction (or forward directions).

As described above, according to the present invention, even if the product solidified or liquidized in the casing prevents

the pump rotor from being rotated, the product is removed by the pump rotor which is rotated in accordance with the predetermined pattern. Therefore, the vacuum pump can be started normally.

Industrial Applicability

The present invention is applicable to a vacuum pump and a method of starting a vacuum pump, and more particularly to a vacuum pump for evacuating a gas from a chamber used in a semiconductor fabrication apparatus or the like, and a method of starting such a vacuum pump.